Concrete Heritage: Challenges in Conservation

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Abstract

The development of concrete in the 19th & 20th centuries led to new possibilities and advancement in construction. Concrete was exploited to address the post-war needs for economical and faster construction. Significant reinforced concrete structures are recognized as cultural heritage. Long term durability problems present conservation challenges and the understanding of failure mechanisms is fundamental for restoration. The diagnosis of historic structures, materials investigation, monitoring and assessment are important steps towards the understanding of deterioration and appraisal of concrete heritage. Long-term effects of conservation and repair also need to be considered. The assessment of concrete heritage is addressed through military and industrial heritage concrete structures in Malta, including coastal structures in aggressive environments. A methodology for appraisal is proposed taking into consideration materials and structural performance and degradation mechanisms.

Keywords: *degradation mechanisms, appraisal of concrete heritage structures, industrial heritage, military heritage.*

Introduction

The development of reinforced concrete towards the end of the 19th century and early 20th century led to significant advances in materials and structural systems. However, reinforced concrete structures started showing signs of degradation with time. Modern standards for reinforced concrete structures refer to the working life of structures and durability design with reference to exposure in different environments. There has been a growing awareness on concrete heritage structures over the past decades with a drive for their conservation. Yet, the conservation of heritage concrete structures presents major challenges. A fundamental step in the conservation of heritage structures in concrete is the appraisal of the materials and structure and the understanding of degradation mechanisms. The challenges and approach to conservation of concrete heritage is discussed with reference to unique industrial and military concrete structures in the Maltese Islands, including structures exposed to an aggressive marine environment.

Conservation of Concrete

Reinforced Concrete has developed as a predominant construction material in the 20th century and the appreciation of modern heritage structures draws attention to the conservation of concrete. There are significant challenges in reconciling the repair options and possibilities with the conservation needs of reinforced concrete structures. Cunstance Baker et al., 2015 note that methods and materials in industry may not take into account the conservation principles of minimal intervention and the retention of the original fabric, resulting in a significant impact on the appearance and materiality of the concrete (Custance Baker et al., 2015). The understanding of the behaviour of the materials in the historic concrete structure and the long term effects of conservation and repair are core issues in defining effective solutions to technical problems presented by deteriorating concrete.

Conservation

The ICOMOS Charter, Principles for the Analysis, Conservation and Structural Restoration of Architectural heritage (ICOMOS, 2003) refers to the value of architecture heritage which does not concern only the appearance but also the integrity of all components as a unique product of the specific building technology of its time (ICOMOS, 2003). For the development of a conservation strategy, the problems leading to the current state of a building need to be understood for each particular case, including historical information such as its use during its history in a particular environment. The investigation needs to identify the cause of the degradation mechanisms and any intervention needs to address this (MacDonald, 2001). An inadequate knowledge of the cause of degradation and the heritage significance of the building can lead to inadequate repair which can have a negative impact on the architectural, historical and cultural significance of the structure (MacDonald, 2003). There can be limitations to the assessment of materials and structures in the investigation of heritage buildings, promoting non-destructive assessment and reducing the extent of destructive testing of materials such as concrete coring. Fundamental principles in conservation including minimal intervention, maximum retention of original fabric and retreatability need to be revisited in the case of concrete. Unlike stone, concrete is monolithic and presents different challenges for conservation. The approach normally adopted in the conservation of stone structures therefore needs to be reconsidered when addressing the complexities of concrete structures.

Degradation of Concrete

Degradation of concrete and reinforced concrete depends on various factors including the constituent materials used in the production of concrete, the relative mix proportions, production process and construction methods, casting and curing, actions on the structure, structural design and detailing, environmental exposure, interventions over the years and maintenance of the structure during its life time. Degradation in concrete occurs as a result of chemical, physical and biological action (Mehta et al., 2006). The penetration of fluids through the microstructure of concrete leads to different degradation processes in the materials including concrete carbonation and chloride induced corrosion particularly in marine environments. Current design codes present durability design of reinforced concrete structures. EN206 presents the exposure classes to be adopted for structures exposed to different environmental conditions (EN 206). EN1990 refers to the design working life and durability of structures (EN1990). The Structural Eurocode 2 for the design of reinforced concrete structures includes requirements for durability design related to exposure classes, through detail design and cover to reinforcement (EN1992).

Repair and Conservation

Repair interventions are presented in EN1504 including surface treatment; patch repair relying on repair mortars and polymer based materials; injection including epoxy injection; electrochemical repair including re-alkalisation, desalination and chloride extraction; cathodic protection; external strengthening (Raupach et al., 2014). It is argued that a successful repair is very difficult to achieve (Vaysburd, 2006) and the premature failure of repair interventions can be attributed to incorrect diagnosis of the underlying problem, incorrect design of repair, poor workmanship, incorrect repair materials and failure to follow manufacturer specifications on the use of repair materials (Tilly et al., 2007).

The repair of structures is distinguished from conservation. In repair, the objective is to preserve structural and serviceability functions, replacing damaged concrete with mortar, concrete or sprayed concrete (shotcrete) to regain strength, density and durability as presented in EN1504 (EN1504, p.9, 2008). On the other hand, conservation refers to all measures and actions aimed at safeguarding tangible cultural heritage, while ensuring its accessibility to present and future generations. Conservation embraces preventive conservation, remedial conservation and restoration. All measures and actions should respect the significance and the physical properties of the cultural heritage item (ICOM, 2008).

There are different options for intervention on structures including: considering a degraded ruin without intervention; reassembled structure and anastylosis; reinstatement using contemporary materials; reconstruction adopting original techniques; reconstruction using new materials; design of a new structure interpreting the historical structure. Different situations require a specific intervention, towards the conservation of reinforced concrete heritage.

Appraisal of Concrete Structures

The appraisal of concrete structures is an important step towards conservation. Any intervention strategy needs to be well informed in order to ensure that the right actions are undertaken to ensure the structural safety, material performance and longer term performance of the restoration interventions. The assessment is intended to provide sufficient information to prepare an intervention strategy for conservation. The appreciation of concrete and reinforced concrete structures requires a clear understanding of the purpose of the structure and its significance, the design, elements, materials and structural systems, actions on the structure and the environment.

The ACI 364.1R presents a guide for the evaluation of concrete structures prior to rehabilitation (ACI 364.1R, 1999). The structured methodology is based on: a preliminary investigation, detailed investigation including documentation, field inspection and condition survey, sampling and material testing; documentation with respect to design, materials, construction and service history. The evaluation is required to cover the structure and its components, geometry, materials, structure rehabilitation options and alternatives and cost. Concrete structures in service need to be inspected at intervals in order to determine their performance and possible degradation (ACI 201.1R, 2008). Furthermore, the inspection is supplemented with other investigations including non-destructive and destructive tests, especially when deterioration is observed.

The assessment of structures refers to key steps intended to compile sufficient documentation which enables the understanding of the behaviour of the structure and degradation mechanisms:

- Records and Documentation
- Classification and Mapping of Degradation
- Materials Assessment
- Structural Assessment
- Environmental Assessment

Records and Documentation

The records on the structure are compiled through archival research and also through an understanding of the use of the structure over time, its conditions and history. Such records include the architectural design, materials including constituent of concrete and mix design, structural drawings and detailing of the structure, construction systems and any alterations and modifications at the time of construction or interventions including repair and maintenance during the service life of the structure.

Classification and Mapping of Degradation

The cataloguing and mapping of defects is necessary to present a clear picture of the state of all the parts of the structure and better relate defects to actions on the structure. Photogrammetric techniques, laser scanning and other advanced technologies are employed in documenting and recording the state of the structure at a particular time and in creating a 3D visual representation of the structure. Such techniques are also employed over time to monitor progression of degradation.

Assessment of Materials

The materials assessment is based on non-destructive test methods and testing on materials extracted from the structure itself.

Non-destructive techniques provide useful information on the state of the structure. The techniques adopted include sounding, Schmidt hammer assessment, cover meter survey, ground penetrating radar, ultrasonic techniques, resistivity, half-cell corrosion assessment, surface moisture and thermal camera.

The definition of the existing materials in the structure is an important first step and includes petrographic analysis and material characterisation through various techniques including Chemical analysis, X-Ray Fluorescence, X-Ray Diffraction, Fourier-Transform Infra-Red Spectroscopy, Electron Scanning Microscopy and Energy Dispersive Spectroscopy. In addition, X-Ray Tomography and Mercury Intrusion Porosimetry are also employed to define the microstructure, the pore structure and pore-size distribution of the material which also relate to its behaviour with respect to transport mechanisms and degradation processes.

Structural Assessment

The structural assessment is based on non-invasive assessment such as micro-tremor investigation and also structural assessment of the structure including finite element modelling. The micro-tremor ambient noise investigation using accelerometers can be compared to the results of the structural modelling, therefore defining the structural performance. The structural modelling enables the assessment of different load combinations and actions on the structure and its elements, and the assessment of the original structure, the degraded one and also repair scenarios. This is a useful tool in assessing performance not only of the structure in the degraded state but also considering repair options.

Environmental Assessment

The assessment of actions on the structure is of importance since structures exposed to different environmental conditions manifest different durability performance. Structures in coastal areas are exposed to air-borne salts whilst coastal structures including harbour infrastructure are exposed directly to saltwater, among other actions. The location and orientation of structures need to be considered as a result of the effects of ground conditions including sources of contamination, the influence of solar radiation, prevailing winds and other actions on durability performance.

Industrial and Military Heritage Structures in Malta

The assessment of degradation of concrete and reinforced concrete structures is presented with reference to key representative structures in the Maltese Islands where the methodological approach defined above has been employed to first understand the state of the structures and then present a strategic framework for intervention in line with the conservation of concrete and reinforced concrete structures. The structures have been classified into two groups: Industrial Heritage and Military Structures, even though there is a clear overlap in various cases.

Industrial Heritage

Concrete and reinforced concrete were extensively used in industrial structures in Malta in the early 20th century Reinforced concrete could provide for larger spans and slender columns to address the need for open spaces in industrial buildings. It was also exploited in infrastructure works including water retaining structures and reservoirs as a result of its versatility. These applications may also result in increased exposure of the concrete and reinforced concrete to aggressive environments.

Water Tower at the Civil Abattoir in Marsa

The Water Tower at the Marsa Public Abattoir was constructed in the 1930s to serve the needs of the abattoir. It is the only structure of its type and size in the Maltese Islands and is considered as an important industrial heritage monument.

The structure had been considered for demolition as a result not only of its severe degradation but also because of the development of alternative means of storing water in reservoirs and supplying water within the abattoir facilities (MRRA, 2011). The case for the conservation of the unique water tower was made in 2010 and presented through a technical report to the Ministry for Resources and Rural Affairs in 2011 (Borg, 2011). Its conservation and restoration were entrusted to the University of Malta, following an agreement for collaboration between the Ministry for Sustainable Development the Environment and Climate Change, the Lands Authority and the University of Malta in October 2016. Its restoration was approved by the Planning Authority in 2017, following a full development permission for its restoration and strengthening based on innovative techniques which address the particular needs of the structure (Borg, 2017).

The Water Tower consists of a large reinforced concrete structure, c.14.5 m high with a tank having an internal diameter of c.9.5m. The tank consists of a shell structure with a cylindrical drum resting on a truncated conical structure with a dome at the base and with ring beams at the top and between each element. The tank rests on a ring beam supported on 12 slender reinforced concrete columns with a reinforced concrete foundation ring at the base. The structure has been repaired in the 1970s and the repair intervention included the strengthening of the 12 columns using a reinforced concrete jacket.

There is evidence that it used to be filled in with brackish and sea water. The age of the structure including the use of sea water in the tank, its location close to the sea in the industrial area of the Grand Harbour and other aspects have contributed to its degradation. This is primarily due to the corrosion of its reinforcement, extensive on the south facing side of the tank. Carbonation of concrete and chloride ion penetration through the concrete structure resulted in the corrosion of reinforcement, cracking, spalling and delamination with loss of concrete section and loss of reinforcement. The combined effects of corrosion-related processes, wet and dry cycles and stresses in the structure in operation, all contributed to degradation.

Figure 1a. Reinforced Concrete Water Tower, Public Abattoir, Marsa, Malta.

Figure 1b. The upper part of the structure consisting of a reinforced concrete tank.

Figure 1c. Aerial view of the water tower.

Figure 2a. Degradation on the south face of the tank, corrosion of reinforcement, spalling and delamination of concrete.

Figure 2b. The interior of the tank.

Water Tower at the Gżira Pumping Station

A master plan for the creation of domestic fresh water and sewer infrastructure for the Grand Harbour area, its suburbs and the North Harbour area was prepared by British Civil Engineer Osbert Chadwick in the late 19th century. The Gżira Pumping Station consists of a Neo-Gothic building designed by Prof. Giorgio C. Schinas and served as the Water and Sewer Pumping Station for the North Harbour area. Together with Royal Engineer Captain T.J. Tressider, Schinas constructed the fresh water and sewer infrastructure for the North Harbour Area. The water and sewer pumping station is a Grade 1 national monument.

The reinforced concrete water tower within the precincts of the pumping station was probably constructed in the second half of the 20th century. The structure continued to be used until the late 20th century and early 21st century. The water tower is c.6m high and the cylindrical drum tank is c.2m high with an external diameter of c.3m, resting on a ring beam supported by four, c.3.5m high inclined reinforced concrete columns. The main cause of degradation is concrete carbonation resulting in loss of passivation, corrosion of reinforcement and spalling and delamination of the concrete. As a result of the degradation of the four reinforced concrete columns, an additional four columns were constructed as temporary supports using concrete blockwork. The structure is one of the few examples of reinforced concrete water towers in Malta.

Figure 3a. Water Tower at the Gzira Pumping Station, Malta.

Figure 3b. Water Tank.

Figure 3c. Degradation in the water tank and ring beam including cracking and spalling as a result of the corrosion of the reinforcement.

Bridge at the Mġarr ix-Xini Pumping Station, Gozo

Engineer Osbert Chadwick had been requested to conduct an inspection of the supply of water in Gozo in the late 1880s by Lieutenant Governor Hely-Hutchinson. At the time, the supply of water relied on natural springs. Due to a sudden shortage of water, in January 1888 an immediate project was assigned to G.C. Schinas to pump water from the Għajnsielem springs to Victoria and other villages in Gozo. In 1897, Chadwick re-proposed the Mġarr ix-Xini water pumping station as the Għajnsielem springs were running low. The Mgarr ix-Xini freshwater pumping station located in the valley was constructed in the 1890s under the Colonial Government for the pumping of mean-sea level ground water and included the excavation of a system of galleries 4,600 feet long. It served as the main source of drinking water in Gozo in the late 19th, early 20th century with the extraction of 190,000 gallons of water per day.

Two pipelines were constructed to supply water from the pumping station to a reservoir in Ta' Ċenċ and another one to Nadur. The pipeline transporting water to Nadur was supported by a bridge across the valley. This bridge still stands today within the valley basin in front of the pumping station, intended to support a cast iron pipe from the pumping station across to the other side of the valley into a tunnel and a trench up to the reservoir in the village of Nadur. The bridge consists of three arches supported on columns resting on the valley bed. A new pumping station was constructed in Xewkija in the 1960s and the galleries were deepened for water to be redirected to the Xewkija pumping station. The Mġarr ix-Xini station was abandoned and is in a state of disrepair (Galea, 2016). In general, the bridge is overgrow with vegetation and the pipework and its supports are damaged, but the structure itself does not show major signs of degradation.

Figure 4a. The Mgarr ix-Xini pumping Station.

Figure 4b. The three arched concrete bridge intended to support the water pipeline, crossing the valley.

Military Heritage

Fort Ricasoli Gun Emplacements and Fire Control Towers

Fort Ricasoli was built at the entrance of the Grand Harbour in 1670, based on a design by Engineer Antonio Amurizio Valperga. The fort was strengthened further during the 18th century and during the last years of the Order's rule on the island. The British noted the forts' important location and armed it strongly with various interventions. In the years prior to the Second World War, Fort Ricasoli was re-armed with three twin 6-pdr QF guns in metal turrets. The emplacements were located on the Ricasoli Fort Bastions no. 2, 3 and 4. Each emplacement had a high concrete fire control tower at the back. In addition, the rear of the gun turrets was protected by a concrete apron. It consisted of a circular covered passageway with columns along the gun emplacement and a reinforced concrete wall at the back to provide gun-crew with overhead protection. An underground magazine was located beneath the emplacement. The construction of the twin 6-pdr QF gun emplacements with their characteristic high fire control towers on the bastions were the final phase of the fortification of Fort Ricasoli in the 1930s, prior to World War II (Spiteri, 1996).

The structures are immediately on the sea, exposed to air borne salts and to an aggressive XS marine environment. (EN206). The structure experiences extensive reinforcement corrosion, concrete spalling and delamination resulting in the extensive loss of sections. Since the structures include large concrete sections typical of a number of military heritage defence structures, they are still in a relatively stable condition though suffering severe degradation.

Figure 5a. The Bastion No.4, twin 6-pdr QF gun emplacement with the characteristic high fire control tower at Fort Ricasoli.

Figure 5b. The passageway and overhead protection at the back of the twin 6-pdr QF gun emplacement at Fort Ricasoli, with severe degradation.

The Acoustic Mirror, Magħtab

Passive early warning systems were developed towards the end of the 1920s and early 1930s, in the form of large reinforced concrete structures intended to pick up the noise of an approaching aircraft from a considerable distance away. The sound received by the large dish-shaped structure was amplified and focused by a probe placed at the centre of the structure, to a central listening position. The acoustic mirror equipped with different sound detectors could listen to and get a bearing of the detected sound, enabling the calculation of the position of its direction (Abela, 2014). A major setback was the fact that the mirrors picked up all sounds. Acoustic mirrors still stand at Denge on the Dungeness peninsula and at Hythe in Kent and other parts of Britain. Acoustic mirrors were also planned to help protect key colonies, namely Gibraltar, Malta and Singapore. Surveys were undertaken in Malta in 1933 and five suitable sites were identified around the coast. The ideal site had to be sheltered from noise from behind and from the sides as well as from the breaking waves of the sea. Five sites were proposed in Malta but one mirror was constructed, in Magħtab, approximately a mile inland with cliffs behind facing out to sea towards Sicily at a bearing of 20 degrees. It was constructed in autumn 1934 and works were completed during the summer of 1935. The electrical equipment was installed in September 1935. The cost of the mirror reached c.4500 Pounds. The Magħtab Acoustic Mirror (Widna) is a copy of the Denge acoustic mirror with minor differences such as small projecting buttresses at the foot of the face of the mirror, reported to detract from its performance. The parabolic concrete surface is a strip from a sphere with a 150 feet radius and measures 200 feet horizontally and 27 feet in height. A 55 feet concrete platform slopes down to a listening trench picking sound from 18 microphones. Trials established that the mirror had a range of 21 to 37 miles, with an average of 25 miles and a bearing error of +/- 2.5 degrees, providing a 6 minute warning of an enemy aircraft approaching Malta at 25mph. The Magħtab mirror was reported to be out of use by t5th May 1937, as a result of the development of RADAR as an active early warning system.

The Acoustic Mirror in Magħtab is protected by the Planning Authority as a Grade 2 Scheduled property. The structure consists of the large parabolic concrete wall with buttresses at the back, small buttresses at its base on the front side and a large sloping platform in front leading to a trench.

The structure still retains its distinctive red, white and green paint pattern on the surface and is in general in a good state of repair. Though not located immediately on the sea, the structure is mainly exposed to airborne salts and moisture from the ground. A catalogue of defects was compiled for the structure and degradation mapping was undertaken for the entire structure. This exercise was followed by non-destructive assessment of the structure based on sounding, Schmidt hammer, ultrasonic pulse velocity, surface moisture and cover meter investigation. The main degradation was mapped for the entire structure. Spalling of the concrete was mapped in specific areas on the front wall, together with spalling and delamination in the lower parts of the reinforced concrete buttresses at the back. The degradation is associated with concrete carbonation resulting in loss of passivation and corrosion of reinforcement, higher moisture content in the lower sections, in particular along the buttresses on the south face.

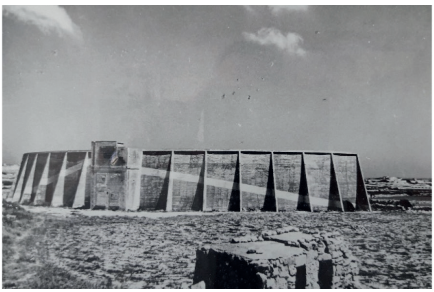

Figure 6a. The Magħtab Acoustic Mirror buttressed structure from the back.

Figure 6b. The Magħtab Acoustic Mirror structure front view.

Figure 7a. The Magħtab Acoustic Mirror buttressed structure from the back (2017).

Figure 7b. The Maghtab Acoustic Mirror structure front view (2017).

Pillboxes and Beach-posts

The threat of invasion caused by the Abyssinian crisis in 1935 led to the construction of a number of pillboxes for the purpose of defence in Malta. Improvised pillboxes were first built, but a network of pillbox defence structures was laid down in the following years in a report on the Malta Defences by the Joint Overseas and Home Defence Committee (JDC No. 280), where point No. 15 in the list of priorities laid down in 1936 emphasized the construction of infantry posts on beaches, together with the emplacement of 12-pdrs for beach defence. The report recommended that sector posts and CWP Concealed weapons posts were to be constructed at all likely landing places to act as a deterrent in spite of the enemy knowing of their existence. The real concentrated scheme for pillboxes building began in August 1938, and proceeded incrementally in stages nearly up to 1942 (Spiteri, 1996).

Early pillboxes were constructed in north Malta which was exposed due to the landing bays and lack of fortifications and coastal defences. The first group of pillboxes were stone-clad pillboxes constructed from1935 onwards in Northern Malta, intended to strengthen the defences of the areas in preparation for an Italian invasion. The field defences and stone-clad pillboxes were concentrated around the major bays in the North. 1938 marks the beginning of the programme of pill-box construction in Malta. Fort Campbell at Selmun, built in the period 1937-1938, was equipped with concrete machine gun posts along its perimeter wall.. Features in the pillboxes included mounting of the defence armament involving semi-circular concrete tables and gun-crew benches. The structures were camouflaged using rubble stone cladding. By 1939, defence lines of pillboxes were established and around 80 beach posts, defence posts, reserve posts and gun posts were reported in early 1940. This number increased considerably in the following years up to 1942, covering most of the Island.

The first pillboxes constructed can be distinguished from their elaborate camouflage using rubble stone cladding to the concrete structure, blending in with the surrounding rubble walls and rural structures. This represents also a continuation of the practice of erecting rubble wall parapets in trenchlike field defences in earlier years. From late 1939 onwards, the time-consuming rubble clad camouflage construction was discontinued and paint work on the concrete was applied instead. The stone cladding, plan adaptation to site requirements and curved fronts and rounded edges were abandoned in favour of pillboxes built in more geometric and standard structures. This reflected a greater sense of urgency, manifesting itself in rapid construction because of the growing threat of war and invasion. By 1939, the second group of pillboxes appeared as reinforced concrete structures, polygonal or rectangular in plan with a bare concrete finish. These box-like structures were more difficult to conceal in a predominantly flat land and were therefore disguised as rural structures and farmhouses with camouflage in the form of paint work including doors and windows on the concrete surface.

Pillboxes mainly consisted of reinforced concrete. Their design varied but nearly all had a rectangular observation cupola with all round vision slits or with a distinct turret on the side (Wied Dalam Pillbox). The supply of cement was limited so minimum sufficient thickness of walls and roofs were imposed for the maximum amount of pillboxes possible. Typically, the concrete is 15 inches thick. Curved corners were desirable because of ballistic standards but were rarely constructed due to the pressing conditions. The concrete was reinforced with 3/8'' reinforcement at approximately 3'' spacing horizontally and vertically.

All pillboxes show significant signs of degradation though inland structures are in a better state than structures on the coast. Beach posts exposed to an aggressive marine environment show severe degradation, corrosion of reinforcement, spalling and delamination, and frequently loss of section. Some of the structures are observed to include sea-shells and pebble aggregate probably sourced from the nearby beach contaminated with sea water and a low quantity of cement, probably due to the pressing needs of construction over short timeframes with limited resources available. Some of the structures built in the later years during the war were also built under pressing conditions and manifest even greater degradation than structures built earlier in the 1930s. The state of the structures and the inherent defects in the materials and structure, present significant challenges for the conservation of these structures today.

Figure 8a. Wied Dalam PillBox.

Figure 8b. Xghajra PillBox.

Figure 9a. Mistra PillBox.

Figure 9b. Rinella Reinforced concrete post.

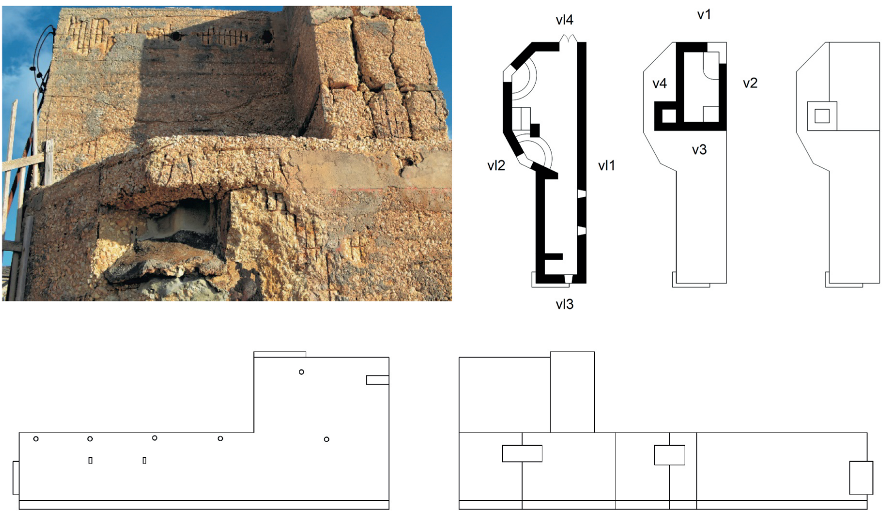

Figure 10. Prajjet, Mellieha Beach Post, degradation of concrete, plans and elevations of the structure.

Conclusion

Concrete repair is important in the rehabilitation of contemporary concrete but it does not automatically satisfy conservation principles which are crucial to the safeguarding of historic concrete and reinforced concrete structures. Structural performance and serviceability criteria need to be addressed if a building is to perform its functions and the durability of the repair intervention itself is of importance.

It is acknowledged that the emerging field of conservation of concrete and reinforced concrete structures presents new challenges to the scientific community and there is limited experience in conservation case studies and long-term performance of interventions; no fixed rules can be broadly applied. A successful conservation intervention requires sensitivity to the materials and structure and the need to address specific peculiarities and characteristics of each structure and component. Different structures present different challenges and an interdisciplinary approach with a sound knowledge in materials and structural behaviour is necessary to address the conservation of reinforced concrete heritage.

The Venice Charter states that the conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage (The Venice Charter, 1964). A structured methodology needs to respect the following: principles of conservation; documentation and historic research; scientific and engineering methods; inspection and materials and structural appraisal; material assessment; non-destructive assessment and non-invasive techniques; structural modelling and analysis; definition of restoration intervention options and assessment of the merits and limitations of each intervention; intervention proposal framework assessment; appraisal of the restored structure; long term monitoring of materials and structures.

In the conservation of heritage structures in concrete, the understanding of the structure and the degradation mechanisms in its particular environment are fundamental. The conservation of concrete heritage presents major challenges and an effective approach for intervention requires a structured methodology for the appraisal of materials and structure leading to a thorough understanding of the historic concrete structure. In this context, each structure and part thereof, presents specific needs which require appropriate tailor-made well-designed interventions. This approach requires a sound understanding of materials and degradation mechanisms, technological solutions for intervention and an assessment of the long-term effects of the interventions towards conservation.

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